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TESTS OF PAVING BRICK.

§2. The materials for the following experiments were collected by the writer, but the larger part of the experiments on the brick were made, under the writer's direction, by one of his students, Mr. J. F. Fisher, as a study for a graduation thesis. Mr. Fisher published an extended account of his experiments in "No. 4, Selected Papers of the Civil Engineers' Club of the University of Illinois." Table I, below presented, is a summary of Mr. Fisher's results, as modified by subsequent experiments made by the writer to test certain anomalous results. The writer has also extended the table by including other bricks.

TABLE I.

SUMMARY OF THE TESTS OF PAVING BRICK.

Ref. No.	Selected by	Locality.	Quality.	Transverse Strength—Modulus of Rupture, in lbs. per square inch.	Absorptive Power, in per cents. of the weight of the dry brick.	Specific Gravity.	Crushing Strength of Cubes in lbs. per square inch.	Loss by Abrasion during 3rd half hour, in per cents. of original weight
1	B	A1	Top course	1,712	4.5	2.10	13,085	0.8
2	B	A2	Bottom course.	1,013	8.5	1.90	6,860	2.6
3	B	B1	Top course	1,496	1.3	2.21	10,545	0.7
4	B	B2	Bottom course.	1.243	5.9	2.08	9,925	2.0
5	B	B3	Old product	1,686	4.8	2.11	9,820	2.5
6	M	C	....	1,680	1.2	2.21	5,260	0.4
7	M	D	....	1,247	7.1	1.98	5,691	3.0
8	M	E	....	1,333	2.6	2.12	5,468	1.3
9	M	F	....	1,790	6.1	2.15	9,494	1.9
10	B	G1	Old product	1,187	12.5	1.74	5,185	3.7
11	B	G2	New product	1,429	4.8	1.87	6,490	....
12	M	H1	New product	2,120	3.5	2.24	8,230	1.2
13	M	H2	Old product	....	2.5	2.26	5,890	1.2
14	B	I	....	1,000	2.0	....	3,460	0.5

§3. Invitations were sent to all the principal makers in all places where it was known that especial attention was given to the manufacture of paving brick, asking them to contribute samples. Not all responded, but samples were received from the following places, viz: Bardolph, Ill., Bloomington, Ill., Charleston, W. Va., Columbus, Ohio, Decatur, Ill., Galesburg, Ill., Sergeant Bluff, Iowa, London Mills, Ill., and Urbana, Ill. This order of arrangment is not that given in the tables, the latter being purely accidental. For obvious reasons it would be improper to identify the several lots; but it is interesting to know that the brick tested included samples from the best known makers in Illinois, and from some of the most prominent makers of other States. It is important to notice that, with the possible exception of brick No. 15 (see Tables II and IV), *all the bricks experimented upon have been tested by actual service in the pavement, and in every case given entire satisfaction.* This phase of the subject is referred to further on in this article.

The second column of Table I shows by whom the samples were selected, those marked B being selected by the writer and those marked M by the maker thereof. The third and fourth columns of the table explain themselves. With one or two unimportant exceptions three or more samples were tested.

TRANSVERSE STRENGTH.

§4. The experiments to determine this element were made on a Riehle Brothers' testing machine in the Testing Laboratory of the University of Illinois. The bricks were supported on knife edges 6 inches apart, and the load was applied by another knife edge brought to bear midway between, and parallel to, the other two.

The modulus of rupture was computed by the formula:

$$W = \frac{2\,b\,d^2}{3\,l} R,$$

in which W represents the load, in pounds; b, d, and l, the breadth, stone it is the uniform practice to test cubes whose faces are carefully dressed to parallel planes; but there is no settled custom as to the manner of testing brick. (1) Some experimenters test half bricks, while others test whole ones; (2) some grind the pressed surfaces accurately to planes, and some level up the surfaces by putting on a thin coat of plaster of Paris, while others leave them in the rough; and (3) some test the bricks set on end, some on the side, and others laid flatwise.

1. From a series of experiments* on soft bricks, the writer concludes that the crushing strength per square inch of a quarter of a brick is about *half* that of a whole one, a half brick is about *two-thirds*, and *three-quarters* of a brick about *five-sixths*, as strong per square inch as a whole one; or, in other words, the strength of a quarter, a half, and three-quarters of a brick, and a whole one, are to each other as 3, 4, 5, and 6 respectively. The reason for this difference is apparent if a whole brick be conceived as being made up of a number of cubes placed side by side, in which case it is clear that the interior cubes will be stronger than the exterior ones because of th side support derived from the latter. The important effect of this lateral support is shown by the fact that if pressure be applied to a square inch in the middle of the upper face of a brick, the resistance to crushing will be ten to twenty times greater than if the parts of the brick not directly under pressure were removed, *i. e.*, if the portion under pressure were deprived of its lateral support. The quarter brick and the half brick have less of this lateral support than the whole one, and hence have a correspondingly less crushing strength.

2. The strength of the specimen will vary greatly with the degree of smoothness of its bed surfaces. To determine the difference between reducing the pressed surfaces to a plane and leaving them in the rough, the writer selected six bricks of regular form

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and apparently of the same strength, and tested three in the rough and the other three after having reduced the pressed surfaces to planes by laying on a coating of plaster of Paris, which, after drying, was ground off to a plane. The amount of plaster remaining on the surfaces was just sufficient to fill up the depressions. Both sets were tested in a hydraulic press between cast-iron, parallel (self-adjusting), pressing surfaces. The average strength of those that were plastered was 2.06 times the strength of those that were not plastered. Other experiments show that if the pressed surfaces had been ground perfectly flat, the strength would have been increased ten per cent. more.

3. As before stated, some experimenters test brick flatwise, some edgewise, and some endwise. The strength endwise is about half to two-thirds of the strength flatwise; and the strength edgewise is about three-quarters of the strength flatwise.

All the above shows how indefinite it is to say that the crushing strength of brick is so much per square inch, and not give full details as to the manner of obtaining such results. The writer is decidedly of the opinion that as a test of the quality of brick or stone the crushing strength is practically worthless. Possibly there are those who believe that it is necessary to test the crushing strength to prevent brick which are so soft as to be crushed by the wheels of vehicles from getting into the pavement. Let us see if this is probable. The crushing strength of a cube cut from a good paving brick is, say, 8,000 to 10,000 pounds per square inch, and if the pressure is applied on only a portion of the upper surface the strength is about twice as much. The surface of contact between a wheel having a 1½-inch tire loaded with half a ton is roughly about one square inch, which gives a pressure on the brick of only 1,000 pounds per square inch. Therefore there is no danger of the brick being crushed.

The crushing test was made in these experiments simply and solely out of deference to custom. *If* the crushing strength could be accurately determined it would be of value in determining the relative strength, and hence would be useful in comparing the quality of different brick.

The results for the crushing strength given in the table were obtained by crushing approximate cubes between self-adjusting parallel cast-iron pressing surfaces, the pressed surfaces of the specimens having been made plane either by grinding on an emery wheel or by laying on a coat of plaster of Paris.

RESISTANCE TO ABRASION AND IMPACT.

§ 8. The abrasion and impact tests were made by putting the bricks and a number of pieces of iron into a revolving horizontal cylinder. The cylinder was a foundry rattler having wooden staves and iron heads, three feet nine inches long by twenty-six inches in diameter, and revolved at the rate of twenty-four revolutions per minute. The iron used consisted of five hundred and forty-six pieces of smoothly worn "foundry shot" averaging about one-sixth pound per piece and having a total weight of eighty-three and one-half pounds.

The writer has seen reports of abrasion experiments in which the brick were "tumbled" with much larger pieces of iron than those used in these experiments. In some cases brake-shoes, weighing anywhere from five to fifteen pounds, have been used, "the loss being determined by weighing the larger pieces of brick." Apparently this indicates that the pieces of iron were so large as to break the brick to pieces.

An abrasion test conducted with large pieces of iron does not fairly represent the conditions in the pavement. In the latter the bricks are supported on all sides except one, and are subjected to pressure and percussion on this side; while in the experiments the bricks are probably broken by blows on the flat side—and possibly this too when the brick is supported only at the ends. In the experiments here reported small pieces of iron were used in the belief that many small pieces more nearly represented the conditions in the street than would a small number of large pieces.

When using large pieces of iron in the rattler, it is customary to tumble the specimen only five or six minutes. Obviously the longer the experiments are continued the more likely will all pieces be worn equally. Hence in these experiments the rattler was run three separate half hours. The average loss for each half hour, in per cents. of the weight of the original bricks, are given in Table II.

TABLE II.
RESISTANCE OF BRICK TO ABRASION AND IMPACT.

Ref No.	Selected by.	Locality.	Loss in per cents. of the original weight, during			Total Loss during	
			1st half hour.	2ndhalf hour	3d half hour.	1st, 2nd and 3d half hours.	2nd and 3d half hours.
1	B	A1	2.0	0.8	0.8	3.6	1.6
2	B	A2	4.9	3.0	2.6	10.5	5.6
3	B	B1	2.1	1.3	0.7	4.1	2.0
4	B	B2	3.6	2.5	2.0	8.1	4.5
5	B	B3	5.0	3.2	2.5	10.7	5.7
6	M	C	0.5	0.3	0.4	1.2	0.7
7	M	D	6.3	3.5	3.0	12.8	6.5
8	M	E	3.1	1.5	1.3	5.9	2.8
9	M	F	4.5	3.1	1.9	9.5	4.0
10	B	G1	5.7	4.1	3.7	13.5	7.8
11	B	G2	....	....	....	....	....
12	M	H1	4.2	2.0	1.2	7.4	3.2
13	M	H2	3.3	1.6	1.2	6.1	2.8
14	B	I	4.5	1.4	0.5	6.4	1.9
15	M	J	2.4	1.0	1.0	4.4	2.0

In considering these results it is necessary to remember that the loss will decrease as the corners and edges become rounded, and that the rate of this decrease will vary with the form and hardness of the bricks. Some manufacturers give their paving brick square corners and edges, while some round the edges a little, and a few champher off the edge considerably. Therefore, for purposes of comparison, the results obtained for the first half hour are the least valuable. Tests for the fourth, fifth, and sixth half hours show that after the third half hour the loss is nearly constant; and hence the results for the third half hour are suitable for use in making comparisons. Taking an average for all the bricks in Table II, and calling the amount lost during the third half hour unity, then the loss during the second is 1.28 and that during the first 2.24. The values given in the last column of Table I (page 3), are for the third half hour.

RESISTANCE OF STONE TO ABRASION AND IMPACT.

§ 9. The above tests for abrasion and impact show only the relative resistance of the brick tested, and give no standard by which to measure the resistance of other brick or of stone. To aid in establishing an absolute standard, and also to afford other experimenters an opportunity of comparing the brick of their locality with those tested as above, *i. e.*, with brick whose durability has been practically demonstrated by long service in the pavement, a number of stones of well known character and which are widely distributed were tested under exactly the same conditions as were the brick.

Table III (page 12), gives the results of the abrasion tests of stone. The pieces of stone were approximately the size and form of the bricks tested. For reasons similar to those stated in discussing the abrasion tests of brick and because in working out the stone specimen the tool used probably deadened the surface of the stone which would cause it to wear off more easily, the results for the loss during the first half hour are not suitable for use in making comparisons. Taking an average of all the stones in Table III and calling the loss during the third half hour unity, the loss during the second is 1.18 and the loss for the first is 1.96. Three samples of each stone were tested. except that only one sample of Nos. 4 and 5 were used.

TABLE III.

RESISTANCE OF STONE TO ABRASION.

Ref. No.	Kind.	Locality.	Loss in per cents. of the original weight during			Total loss during	
			1st half hour.	2nd half hour.	3d half hour.	1st, 2nd and 3rd half hours.	2nd and 3rd half hours.
1	Granite	Quincy, ...Mass	1.5	0.8	0.4	2.7	1.2
2	Granite	Aberdeen, ...Wis	1.1	0.7	0.3	2.1	1.0
3	Granite	Martindale, ...Wis	0.6	0.4	0.3	1.3	0.7
4	Granite	Berlin, Wis..	0.4	0.1	0.03	0.5	0.13
5	Granite	Iron Mountain, Mo..	2.2	0.5	0.4	3.1	0.9
6	Light Cloud Columbian Marble.........	Rutland, Vt	4.4	3.1	2.9	10.4	6.0
7	Drab Sandstone	Berea, Ohio..	9.8	6.1	5.4	21.3	11.5
8	Dolomitic Limestone	Ellettsville, ...Ind	8.6	5.6	4.9	19.1	10.5

All the granites except the first are samples from the street pavements of Chicago. The identification of the pieces was carefully checked. The marble, sandstone, and limestone—samples of well known stones of uniform texture—were included to afford other experimenters further means by which to compare the abrasion of their bricks with those tested as above. Attempts were made to secure other well known stones, but such efforts have thus far failed.

RELATIVE RESISTANCE OF BRICK AND STONE TO ABRASION.

§ 10. Table IV exhibits the loss of the several grades of bricks in terms of the loss of the several stones—all being tested under the same conditions.

TABLE IV.

RELATIVE RESISTANCE OF BRICK AND STONE TO ABRASION.

Ref. No.	Selected by	Locality.	Wear of the Brick in Terms of that of							
			Granite from					Columbia Marble	Berea Sandstone.	Indiana Lime'ne
			Quincy.	Aberdeen.	Martindale	Berlin.	Iron Mt.			
1	B	A1	2.0	2.7	2.7	27.	2.0	0.3	0.1	0.2
2	B	A2	6.5	8.7	8.7	87.	6.5	0.9	0.5	0.5
3	B	B1	1.8	2.3	2.3	23.	1.8	0.2	0.1	0.1
4	B	B2	5.0	6.7	6.7	67.	5.0	0.7	0.4	0.4
5	B	B3	6.2	8.3	8.3	83.	6.2	0.9	0.5	0.5
6	M	C	1.0	1.3	1.3	13.	1.0	0.1	0.1	0.1
7	M	D	7.5	10.0	10.0	100.	7.5	1.0	0.6	0.6
8	M	E	3.2	4.3	4.3	43.	3.2	0.4	0.2	0.3
9	M	F	4.8	6.3	6.3	63.	4.8	0.7	0.4	0.4
10	B	G1	9.2	12.3	12.3	123.	9.2	1.3	0.7	0.8
11	B	G2	....	....	....	....	....	....	....	....
12	M	H1	3.0	4.0	4.0	40.	3.0	0.4	0.2	0.2
13	M	H2	3.0	4.0	4.0	40.	3.0	0.4	0.2	0.2
14	B	I	1.2	1.7	1.7	17.	1.2	0.2	0.1	0.1
15	M	J	2.5	3.3	3.3	33.	2.5	0.3	0.2	0.2

Table IV is found by dividing the amount each kind of brick lost during the *third* half hour by the loss of each kind of stone during the same time. For example, the loss of brick No. 1 during the third half hour, as given in Table II, was divided by the loss of Quincy Granite during the third half hour, as given in Table III, and the result placed in Table IV opposite No. 1 in the column headed Quincy Granite. Since the quantities of Tables II and III are possibly in error nearly a half unit in the last figure, the last figures of the quantities in Table IV can not be relied upon. However, this limitation does not materially alter the value of the table. Of course a similar table could be prepared for any other half hour or any combination of these experiments.

To compare any given brick with those of the above tables, it is only necessary to secure samples of any of the stones in Table III, and test both brick and stone under conditions as nearly similar to those here employed as can be readily obtained. Then deduce a table similar to Table IV, and a comparison between these results and those of Table IV will show the relative resistance of the brick being tested as compared with those in the above table. By this means the qualities of any new candidate for public favor can be compared with an absolute standard, as say, Quincy Granite, and also with any of the above brick—all of which are of demonstrated good quality.

§10*a*. The following data on the resistance of paving brick to abrasion and impact came under the writer's eye after this article was supposed to be completed. The experiments were made by Mr. George Sattler, of St. Louis, about twelve years ago. The data from which Table V was computed were taken from a printed copy of a communication of engineers and citizens to the Board of Public Improvements of St. Louis, relative to brick as a paving material.

TABLE V.

Relative Resistance of Brick and Stone to Abrasion and Impact.

Ref.No.	Kind of Material.	Loss in grains.	Loss in per cent. of original weight.	Loss of the different materials in terms of the loss of		
				Lake Superior Granite.	Missouri Red Granite.	Asphalt Concrete.
21	Lake Superior Granite,..........	120	12	1.0	0.4	0.14
22	Sattler's hard-burned brick.....	180	19	1.5	0.6	0.21
23	Missouri red granite	320	33	2.7	1.0	0.38
24	Sattler's hand-made brick......	324	34	2.7	1.0	0.38
25	Sattler's hydraulic pressed brick..................................	333	35	2.8	1.0	0.39
26	Best St. Louis Limestone........	667	69	5.6	2 1	0.79
27	Asphaltum concrete................	847	88	7.0	2.6	1.00
28	Sterling's side-walk brick......	890	93	7.4	2.8	1.05

The experiments were made by "inserting into a tin can having perforations all over it, 960 grains (2 oz.) of each of the materials, in pieces of equal size, and shaking them many thousand times, and freezing and thawing very frequently," after which the amount remaining in the can was weighed. "These residues, therefore, represent the relative resistaance of the several materials to *impact* and *abrasion*. It will be seen that in this test the bricks of Mr. Sattler stand close to Missouri granite. We give this experiment upon the representation of Mr. Sattler, and have no doubt of its correctness, the case containing the residue having been sent here and, after an examination of the contents to verify the respective weights, handed to the Board for its inspection and consideration."

RELATIVE VALUE OF THE TESTS.

§11. In the first part of this article has been described a method of testing brick to determine the transverse strength, the absorptive power, the specific gravity, the crushing strength, and the resistance to abrasion and impact. It now remains to discuss the relative value of the several tests. Or, in other words, having tested a number of bricks as above, how may we determine which of the several bricks are the best? If the five tests were of equal value, the result could be easily arrived at as follows: Form a table similar Table I (page 4), except that instead of giving the results as in that table give the rank which the bricks have in the several columns of that table. Table VI is formed in this way. Notice that Nos. 11, 12, and 14 are omitted because the record for them is not complete.

TABLE VI.

RELATIVE RANK OF THE SEVERAL BRICKS IN THE VARIOUS TESTS.

Ref. No.	Selected by.	Locality.	Transverse Strength.	Absorptive Power.	Specific Gravity.	Crushing Strength.	Resistance to Abrasion.	For All Tests		For 1st, 2nd and 3rd Tests.	
								Sum of Ranks	Final Rank.	Sum of Ranks	Final Rank.
1	B	A1	3	5	6	1	3	18	3	11	4
2	B	A2	11	10	9	7	9	46	10	30	10
3	B	B1	6	2	2	2	2	14	1	10	3
4	B	B2	9	7	7	3	7	33	8	23	8
5	B	B3	4	6	5	4	8	27	6	18	7
6	M	C	5	1	2	10	1	19	4	7	1
7	M	D	8	9	8	8	10	43	9	27	9
8	M	E	7	3	4	9	5	28	7	15	5
9	M	F	2	8	3	5	6	24	5	16	6
10	B	G1	10	11	10	11	11	53	11	32	11
12	M	H1	1	4	1	6	4	16	2	9	2

If the several tests had equal value, then the number in the third column from the right hand end of Table VI would show the relative quality of the different bricks. But the several tests are not of equal value. In the first place, owing to difficulty in making them the experiments on compressive strength are practically worthless. In the second place, absorptive power and specific gravity depend mainly upon the same quality, *i. e.*, porosity. The value of the absorptive test varies a little with the climate; that is, in a cold climate the absorptive test is of relative greater importance, and in a warm climate of less. The properties that give a great resistance to abrasion are the ones most to be desired in a paving brick; but abrasion tests are not as accurate as tests of absorptive power and of transverse strength, and besides the transverse strength shows one quality, *i. e.*, toughness, which largely determines the resistance to abrasion and impact—particularly the latter. As far as the writer can see, the tests for transverse strength, absorptive power, and resistance to abrasion are of nearly equal value. The last column of Table VI shows the rank for the three most valuable tests.

SPECIFICATIONS FOR PAVING BRICK.

§12. Bricks vary greatly in size and quality, and hence as a mere matter of business prudence it is necessary to have some standard by which to judge of the quantity and quality of the material furnished. As far as the writer has observed, the so-called specifications for paving brick really specify or define nothing. For example, a very common specification is: "The brick must be of the best quality, hard-burned paving brick." Such a requirement puts the manufacturer or contractor at the mercy of the one to whom is given authority to interpret the contract and inspect the material; while the citizens have no definite idea of the quality of brick being used. Practically such a provision is usually a dead letter.

The most definite specifications for this purpose that the writer has seen are the following: "The paving brick shall consist of the best quality of sound, hard-burned paving brick, made and burned specially for street paving purposes; and shall stand all reasonable tests as to durability and fitness, to which paving material is usually subjected. All bricks shall be square edged and straight, free from cracks and other defects, and of uniform size, and of a quality to be approved by the Board of Public Works. Three or more bricks of the kind or quality of brick proposed to be used in the paving shall be furnished with each proposal, the bricks to be labeled with both the bidder's and maker's name and address, and be deposited in the office of the Board of Public Works before the time of opening the bids." Not infrequently a clause is unwisely inserted requiring that the brick shall be burned in a particular kind of kiln. The user of any commodity should simply specify the qualities desired and leave the manufacturer untrammeled in his method of securing that quality.

The latter specifications are better than the former, but do not specify much as to the quality of the bricks to be employed. The fact that a brick is locally known as "the best quality, hard-burned paving brick" is no indication of its quality. A brick called hard in one community, in another may be called soft. In recent years there has been reported a great difference in durability of brick pavement, varying mainly with locality. Probably this difference in durability is due to the difference in the quality of the brick. It is impossible from the description of the brick as usually given, to get any definite idea of the quality of the material employed.

In the variability of the product, the manufacture of bricks and hydraulic cement are very much alike. All engineers in using hydraulic cement are careful to specify not only the conditions which the cement should fulfill, but also the method to be employed in testing whether these conditions are fulfilled. Further, it is unquestionably true that the specifications for hydraulic cement employed by some well-known engineers have done more to improve the quality of hydraulic cement than any other one thing. If brick is to hold its own and grow in public favor as a paving material, it will be necessary to take advantage of all the teachings of science and experience.

One of the points that needs attention in this connection is the establishment of a standard by which to judge of the suitability of any particular brick as a paving material. It is bad business policy for the manufacturer of paving brick to even allow the public to delude itself as to the service to be derived from a particular quality of brick when laid in a pavement. In fact the principal danger in the rapidly increasing use of brick as a paving material is that brick made in the neighborhood will be employed in response to local influence and to the popular cry of helping a local industry, without due regard to the quality of the brick. Hence the manufacturer should be interested in establishing a recognized standard for paving brick. There is a recognized standard for the materials employed in all other branches of engineering. For example, in iron construction the quality of the material, and even the details of the experiments by which this quality is to be determined, are rigorously specified.

Definite specifications are an advantage to both parties to a contract. If the provisions of the contract are loose, one contractor will interpret them one way and put in a bid that can be fulfilled profitably only by using inferior material, while another contractor will interpret them to require first-class material and will bid accordingly. Again, another contractor not knowing the kind of work expected under the loosely drawn specifications, bids at such a price that he can put in first-class work, if it is called for, and takes his chances of being able to satisfy the specificaiions with work of lower quality. Or, taking another point of view, a committee of the city council visits a number of cities to inspect brick pavements, and being well pleased with what they saw order their own streets paved with "hard-burned paving brick," and make no adequate provision to determine the quality and probable durability of the brick employed. With the exception of railroads, the paving of the streets of our cities represents a larger outlay than any other class of public works. Hence the public should be interested in the establishment of a recognized standard for all paving materials. The above experiments were undertaken to determine some absolute standard by which to judge of the quality of paving brick.

§ 13. With Tables I, IV, and VI before the engineer, he can draw definite specifications for paving brick. For example, it would be difficult to conceive of a better paving brick than No. 6. They are truly first class. They are on the market in practically unlimited quantities, and, to the writer's personal knowledge, of apparently as good quality as the samples tested. If this quality is desired, it is only necessary to specify, among other obvious simple conditions, that three (or five) samples taken at random and tested as above shall show a modulus of rupture of 1,600 pounds per square inch, an absorption of 1.5 per cent., and the same loss by abrasion as Quincy granite (or the corresponding quantity for any of the other stones) when both are tested under the same conditions.

If a second quality, but by no means a poor, paving brick is desired, make the specifications agree with the tests of No. 3 or 12 —the two are practically the same;—that is to say, specify that the modulus of rupture shall be 1,400 pounds per square inch, the absorption shall not exceed 4.0 per cent., the loss by abrasion shall not exceed two times that of Quincy granite.

For a third-class brick specify the qualities shown by No. 10; that is, specify that the modulus of rupture shall be at least 1,200 pounds per square inch, the absorption 6 per cent., and the loss by abrasion shall not exceed 6 times that of Quincy granite.

In applying these specifications, it will be necessary to establish a limit below which no brick shall go. For example, the above specification for first-class brick says that the modulus of rupture of three specimens must average 1,600, but it would not be permissible for one to be 600. The writer suggests, *tentatively,* that if the averages specified above are maintained that a variation of, say, 20 per cent. below those quantities be permitted.

§ 14. There are two other items that need consideration in drawing specifications for paving brick. The first is size. A brick is popularly supposed to be 8 inches by 4 inches by 2 inches; but as a matter of fact while nominally of these dimensions they differ considerably therefrom. An apparently slight difference is of greater importance than at first thought it seems. For example, if reckoned according to cubic contents, brick 8x4x2 inches is worth $10 per thousand, brick 8¼ x 4¼ x 2¼ is worth $12.33 per thousand, and 8½ x 4½ x 2½ is worth $15 per thousand. Paving "blocks" much larger than common bricks are sometimes made.

The second of these items is: The clay from which bricks are made frequently contains limestone pebbles, which in burning are changed to caustic lime. Any considerable amount of lime in paving brick is injurious, since a small quantity of water reaching the lime will cause it to slake and disintegrate the brick. Hence it should be specified that the paving brick should not contain enough lime to cause them to crack when immersed in water for, say, 5 or 10 days.

DURABILITY OF BRICK PAVEMENT.

Under this head we will try to find a relationship between the wear of brick in the pavement and the traffic passing over it, and also try to determine a relation between the abrasion tests and the probable durability of the brick in the pavement.

§15. The brick designated No. 1 in the preceding tables were taken from a pavement immediately in front of the platform scales of a coal and grain warehouse. Owing to the width of the scale platform, the wheels were limited to a portion of the pavement about one foot wide. The brick tested were taken from this most worn portion. Probably from one quarter to one half of the wear due to the feet of the horses came upon the same area as that worn by the wheels. It seems to be the prevailing opinion among brickmakers and citizens generally that the chief wear is caused by the horses' shoes. Intelligent engineers have estimated that one third the wear on city pavements in general is due to the horses' feet. A careful study of this particular pavement gave no indication as to the relative effect of the horses' feet and of the wheels. Probably this failure was due to the fact that even the wear due to the wheels was hardly perceptible. The driveway was level.

The pavement had been down thirty-nine months to a day, and in that time 30,734 tons and 54,416 horses passed over it, as shown from the records of the loads weighed. In other words, there passed over the pavement 13,604 loads averaging 1.64 tons, and 13,604 loads averaging 0.62 tons. Each load was drawn by two horses. Excluding the effect of the horses' feet, the traffic was 15,367 tons *per foot of width.*

An examination of the surface of the bricks showed conclusively that the only effect of the traffic had been to wear off the corners and edges of the bricks. This was checked by comparing the depth of the bricks exposed to the traffic, with that of those in unexposed portions of the pavement. The wear of the brick due to the above traffic was estimated, in volume, by five independent observers, the writer being one, and the agreement was astonishingly close. The average loss as thus estimated was 1.01 per cent. Owing to the greater ease with which the square edges of the bricks are broken off, it is probable that the greater part of this wear occurred during the first part of the time; but assuming that the wear was uniform, we see that if 15,367 tons wore off 1.01 per cent., then 15,250 tons per foot of width wore off 1 per cent.

§16. An interesting result was obtained by testing a half dozen "arch" or "eye" brick of the same manufacture as those designated No. 1 in the preceding tables. The bricks tested were removed from a pavement for that purpose. They were much harder burned than those which the maker calls his best pavers, and were what would be called fully vitrified. The bricks were burned in an up-draft kiln with outside fire-boxes; and consequently the bricks were subjected, during burning, to medium drafts of cold air when the fire doors were opened. These drafts chilled the bricks and cause them to crack or check.

These bricks showed a modulus of rupture of 1,593 pounds per square inch, an absorptive power of 1 per cent., and a specific gravity of 2.19. To compare these results with those for other brick, see Table I (page 4).

In the rattler the *softer* three of these bricks showed, for each half hour, one fifth less loss than that recorded for No. 1 in Table II; but all of the *harder* three broke up during the experiments. One of the three that did not break up showed cracks at the end of the third half hour which indicated that it too would soon go to pieces. By far the greater part of the wear took place along cracks or checks which were only revealed in the rattler. This is a very undesirable quality for a paving brick, since it will cause the pavement to wear rough, which is undesirable in itself and which will increase the destructive effect of subsequent traffic. The breaking to pieces in the rattler seems to be fully accounted for by saying that the bricks were brittle. Do the above results warrant the conclusion that "arch" or "eye" bricks are not suitable for pavements?

These bricks had been in a pavement in front of the platform scales of a coal and grain warehouse, for 19 months, during which time 23,293 tons and 42,996 horses passed over the driveway. In other words, there passed over the pavement 10,749 loads averaging 1.54 tons, and 10,749 averaging 0.61 tons, each being drawn by two horses. The traffic was 11,646 tons *per foot of width*, exclusive of the effect of the horses' feet. The bricks tested were taken from that part of the pavement over which the wheels passed. The pavement was on about a 5 per cent. grade, *i.e.*, the pavement had a slope of five in a hundred. One third of the loads were drawn up this grade and two thirds down it. As in the other case, the condition of the pavement gave no indication of the relative wear of the wheels and of the horses' feet.

Under the above traffic, 11,646 tons, the softer three of these bricks lost 0.97 per cent., or 12,000 tons per foot of width wore off 1 per cent, which agrees fairly well with the results above for No. 1. But the harder three had lost only about 0.2 per cent., with a possible (but not a probable) loss of 0.5 per cent. The brick were very rough when laid, so much so that the workmen had to knock off "the whiskers" before laying them. The greater value given above for the loss was deduced on the assumption that all the pieces broken out of the upper surface was due to the traffic. Probably not all of this loss was caused by the traffic, although doubtless some of it was. Notice that in either case the loss is proportionately small and directly opposite to the relative results obtained in the rattler for the harder and the softer of these very hard bricks. Unfortunately it was not possible at that time to make further experiments.

What does this difference of wear in the pavement and in the rattler idicate? The writer is not fully decided in his own mind, but is inclined to believe that these results show that brick can be burned too hard for use in a pavement. It is a common practice to specify that paving bricks shall be "thoroughly vitrified." Vitrified brick are always very hard, and generally also equally brittle and unfit for a pavement. There may be clays which make the best paving bricks when burned to vitrification, but the writer does not remember having seen any such. However, this subject is not now up for discussion, and, besides, the proper course in this respect is to apply tests to the finished product and leave the maker untrammeled in the method of manufacture.

§17. The brick designated No. 10 in the preceding tables had been in service for six years in a pavement which was carrying, *per foot of width,* a daily traffic of 15 one-horse vehicles, 7 two-horse vehicles, and 1 two-ton load. Making the usual assumptions, *i. e.*, that a one-horse vehicle empty or lightly loaded is equal to half a ton, and a two-horse vehicle empty or lightly loaded is equal to 1 ton, the above traffic is equivalent to 16.5 tons per foot of width per day. Therefore, the total wear on these bricks was equivalent to a daily traffic of 99 tons per foot of width for one year. Allowing 313 days per year, *i. e.*, not counting the traffic on Sunday, the total traffic over the pavement was 30,978 *tons per foot of width.*

It should be stated that in this particular case the above estimate of the weight of different vehicles—the one usually made in computations—assigns a weight considerably greater than the actual one. This assumption as to the weight of different vehicles originated in London, where it may have been correct; and it has been adopted in this country apparently without considering whether it correctly represents the facts. In the particular case in hand, the one-horse vehicles were mostly light one-seated buggies, weighing probably about 0.3 tons each, while the average weight of the two-horse wagons was probably about 0.6 or 0.7 tons. If the traffic be reduced according to the last estimates, then the total is equal to 21,400 tons *per foot of width.*

To determine the amount the pavement had been worn away by this traffic, twenty bricks were taken from the *center* of the street, and another twenty were taken from portions of the side of the strret where there had been practically no wear. Each lot was cleaned, dried, and weighed. Those from the center of the street weighed 6.0 per cent. less than the others. It was assumed that the lot from the side of the street represented the average weight of the bricks when they were laid, and that consequently the above difference represents the loss by wear. To check this result, pieces were chipped and filed from the side of the brick that was down in the pavement, to an amount equal to the wear on the top surfaces. This step was checked by submitting the specimens to an intelligent man who was ignorant of the purpose of the test. The brick were then weighed, and the loss computed, which was found to vary from 1 to 8 per cent., the average being 5.37 per cent. The value 6 per cent., found by the first method, was considered the more reliable.

If the first estimate of the traffic be assumed as correct, then 30,987 tons wore off 6 per cent.; or 5,166 tons per foot of width wore off 1 per cent. If the second estimate be taken as the correct one then 21,400 tons were required to wear off 6.0 per cent., and 3,560 tons per foot of width would have worn off 1 per cent.

§ 18. Possibly the following estimates, although not nearly as accurate as those above, may be of some interest. Brick of the same manufacture as No. 10, during fourteen years in a pavement wore off somewhere between a quarter and a half inch of depth. The exact wear can not now be determined, since the original depth of the brick is not known accurately. Neither can the traffic during the fourteen years be determined precisely at this late day. However, a careful consideration of all the conditions seems to show that the loss of this pavement was about 1 per cent. for each 6,000 tons per foot of width passing over it.

Brick No. 5 had been in a pavement for four years, during which time the wear was about 1 per cent. for each 9,000 tons per foot of width.

Brick No. 13 had been in service "near the middle of a street between two large wholesale houses for seventeen years," in a town of an average population of, say, 4,000. The writer has no knowledge as to the amount of traffic the pavement has carried. The bricks tested (they were not selected by the writer), showed very little wear, certainly not more than 5 or 6 per cent. and possibly not half that much.

RELATION BETWEEN SERVICE IN THE PAVEMENT AND WEAR IN THE RATTLER.

§19. Notice that according to Table II, (page 10), brick No. 1 lost 0.8 per cent. during the third half hour in the rattler, and that brick No. 10 lost 3.7 per cent. In the rattler the loss of brick No. 10 was then 4.6 times as much as brick No. 1. Notice also that 15,250 tons (see §15) wore 1 per cent. from brick No. 1, while 3,560 tons (see §17) wore 1 per cent. from brick No. 10. In the pavement then, the loss of brick No. 10 was 4.0 times as much as brick No. 1; while in the rattler, the loss of No. 10 was 4.6 times that of No. 1. Considering the nature and method of investigation, and particularly that the figures for the loss in the rattler are possibly considerably in error owing to omitted decimals, the agreement is reasonably close. This then is a fairly good check upon the preceding investigation.

Notice that brick No. 1 lost 0.8 per cent. in the rattler during the third half hour, and that in the pavement 15,250 tons per foot of width caused a loss of 1 per cent.; therefore, we may assume that the third half hour in the rattler was equivalent to a traffic of 19,000 tons (equal to 15,256 divided by 0.8) per foot of width of pavement. Or, we may reason backward from brick No. 10 to brick No. 1 thus: 3,560 tons wore 1 per cent. from No. 10, and since brick No. 10 lost in the rattler 4.6 times as much as No. 1, then the latter should require 4.6 times 3,560 tons or 16,364 tons to wear off 1 per cent. This is smaller than the result deduced above, but as the tonnage was more accurately measured in the first case that result will be used as the basis of further comparisons. 19,000 tons is the same as a daily traffic of 53 tons for 313 days, *i. e.*, one year omitting Sundays.

The wear of the brick in the pavement is due to three causes, the wheels of vehicles, the feet of the horses, and the action of frost, etc. The effect of the first two is about proportional to the tonnage passing over the pavement, while the last depends mainly upon the length of service and is therefore nearly independent of the amount of traffic. In the examples employed to establish the conclusion of the preceding paragraph, the traffic was comparatively light, and hence the effect of the weather was comparatively great; therefore, if the relation between wear in the rattler and service in the pavement as found in the preceding paragraph, be employed to compute the probable life of brick in a street having a comparatively greater traffic, any error due to the effect of the weather will be on the safe side.

LIFE OF BRICK PAVEMENTS.

§ 20. The first part of Table VII (pages 32-33), gives the data concerning the traffic on several streets of various American cities. The data are from a paper, "An Account of Some Observations of Street Traffic," by Captain Francis V. Greene member of the

American Society of Civil Engineers, published in Vol. 15 pages (123–38), of the transactions of that society. Concerning the method of making these observations Captain Greene says:

"The observations were made under my direction during the months of October and November, 1885, by the employees of the Barber Asphalt Paving Company, which has an office and works in the ten large cities, viz.: New York, Philadelphia, Chicago, Boston, St. Louis, New Orleans, Washington, Buffalo, Louisville and Omaha. In the arrangments for taking two objects were kept in view: first, to leave as little as possible to the judgment of the observer; and second, to make the record permanent, so that it could be preserved for examination in all its details at any time.

"The agent in each city was instructed to select the three streets in that city paved with stone, asphalt and wood (if any existed), which, by common report, had the heaviest traffic in the class of pavement used on that street. The record was in every case made on six consecutive days (Sundays omitted) at the same place, and it was continuous from 7 A. M. to 7 P. M., except when darkness prevented. No addition was made for this omission, no record was kept during the night, and no addition was made as an estimate of night traffic.

"The printed instructions issued to each observer contained the following rules as a guide in estimating weights:

1-horse carriages, empty or loaded.	Less than 1 ton.
1-horse wagons, empty or light-loaded.	
1-horse carts, empty.	
1-horse wagons, heavy loaded.	Between 1 and 3 tons.
1-horse carts, loaded.	
2-horse wagons, empty or light-loaded.	
Wagons and trucks drawn by two or more horses, and beavy-loaded.	Over 3 tons.

"'Special note will be made, in the column of remarks, of any unusually heavy loads, such as 6-horse trucks loaded with stone or iron, and an estimate given of their weight.'

"The traffic is divided into three classes, light weight (less than one ton), medium weight (between one and three tons), and heavy weight (more than three tons); and in order to reduce the personal equation of the different observers to a minimum, the directions specify what classes of vehicles are to be counted in each class of weight. Nothing is then left to the observers judgment and estimation except the question of 'heavy' and 'light' loads in one-horse and two-horse wagons. The result of different estimation in this respect between two observers would simply change a portion of the vehicles by one class, and the error in the final result could hardly exceed five per cent.

"I have discarded the weight of the horses altogether, not because they do not constitute a factor in the wear of the pavement, but because they were discarded in the English reports, and I desired as far as possible to make comparisons with them. The addition that would have to be made if the horses were included would vary with the traffic. On streets where light vehicles predominate (as on Fifth Avenue), the addition to the tonnage by including the weight of the horses would be about 85 per cent.; on streets with heavy vehicles (such as Wabash Avenue, in Chicago), it would be only about 40 per cent.; and for other streets it would be between these two limits.

"The average daily traffic was obtained by dividing the total record for six days by six. To obtain the tonnage, I estimated the light-weight vehicles to average one-half ton each (including their loads), the medium weight two tons, and the heavy weight four tons.* Multiplying the daily average of vehicles in each class by these figures and adding together the products, the total tonnage was obtained; and dividing this by the width between curbs, we get the daily average tonnage per foot of width.

"The average tonnage per vehicle is an almost infallible indicator of the character of the street, *i. e.*, whether devoted to residential or business purposes. It ranges from 0.68 tons on Fifth Avenue to 2.08 on a portion of Wabash Avenue in Chicago. The same character is indicated by the proportions of light and heavy vehicles on the street. On Fifth Avenue, for instance, 91 per cent. of all the vehicles weigh less than one ton, while on Wabash Avenue only 25 per cent. of them have so little weight. The general average for all the cities is as follows: Less than one ton, 67 per cent.; between one and three tons, 26 per cent.; more than three tons, 7 per cent. The average tonnage per foot *in each city*, so far as here observed, varies from 151 in New York to 30 in Buffalo, and the general average is 77. For all the cities in the table, the average daily tonnage per foot of width is 77, and varies from 273 tons on Broadway to 7 tons on a granite street in St. Louis. The average weight per vehicle is, for all the cites, 1.15 tons. The average width of the street between curbs is 44 feet."

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*According to the observation of the writer of this article, in five of these cities during the past summer, this estimate seems to assign too much tonnage to the "light weight" and "medium weight" vehicles.

The only streets of Table VII (pages 32-33), which were paved with wood at the time the observations were made were as follows: in Boston, Devonshire Street; in Chicago, La Salle; and in St. Louis, Chestnut. The others were paved with granite or asphalt. In this connection it is interesting to note that in London some of the heaviest traffic streets, *i.e.*, streets carrying 300 to 400 tons per foot of width, are paved with wood.

§ 21. In the preceding section it was shown that a daily traffic of 53 tons, exclusive of the effect of the horses' feet, wore 1 per cent. from a pavement laid with the brick designated No. 1 in all the preceding tables. The length of service was 39 months; the average weight of the load passing over the pavement was 1.13 tons (see § 15), as determined from the records of loads weighed. Notice that this is almost exactly the average weight of the vehicles observed by Captain Greene.

If a daily traffic of 53 tons wore off 1 per cent. then a pavement laid with the brick designated in the preceding tables as No. 1 and subjected to a traffic of 53 tons per foot of width would nominally last 100 years, and a pavement subjected to twice that traffic would last half as long, and similarly for traffic of any other intensity. In this way were computed the quantities in the column numbered 1 of Table VII (pages 32-33). Brick No. 3 lost in the rattler during the third half hour 3.2 times as much as No. 1, and if we assume that the relative durability in the pavement is the same as in the rattler, then the life of brick No. 3 can be found by dividing the quantity in column numbered 1 (the seventh column) of Table VII by 3.2. In this way was computed column 3 of Table VII, and similarly for the remaining columns.

Of course bricks could not be used in a pavement until they had lost 100 per cent. In one case the writer knows of brick which were originally 2x4x8 inches set on edge that have been worn down half their depth and still give no indication of difficulty in keeping them in place. Therefore it appears that the pavement will last at least until 50 per cent. of the depth of the *upper course* has been worn off, and there are some intelligent men who

TABLE VII.

PROBABLE LIFE OF THE SEVERAL SAMPLES OF BRICK IF LAID IN CERTAIN STREETS OF SUNDRY PROMINENT CITIES.

CITY.	STREET.	Width in feet.	DAILY TONNAGE.			NUMBER OF YEARS REQUIRED TO WEAR OFF 100 PER CENT. FROM THE SAMPLE NUMBERED										
			Total.	Per Vehicle.	Per foot of Width.	1	3	5	6	7	8	9	10	12	14	15
New York	Broadway, near Pine	40	10,905	1.39	273	19	21	8	38	5	12	8	4	13	32	19
New York	Fifth Ave., opposite Worth Mon't	40	3,740	.68	94	56	61	22	112	15	85	24	12	38	93	56
New York	Wall, cor. Broad	27	2,357	1.00	87	60	68	24	120	16	38	25	13	40	100	60
Boston	Devonshire, opposite Post Office	27	5,301	.99	196	27	30	11	54	7	17	11	6	18	45	27
Boston	Devonshire, near Milk	32	5,028	1.02	157	34	37	14	68	9	21	14	7	23	56	34
Boston	Kilby, near State	26	3,265	.93	126	42	46	17	84	11	26	18	9	28	70	42
Boston	Washington	39	2,938	.80	75	70	77	28	140	18	44	29	15	47	116	70
Boston	Arch, near Summer	26	1,130	.79	43	123	135	49	246	32	77	52	27	82	204	123
Boston	Court Square	24	744	.67	32	165	181	66	330	43	103	69	36	106	274	165
New Orleans	Tchoupitoulas, near Poydras	40	6,204	1.81	155	34	37	14	68	9	21	14	7	23	56	34
New Orleans	St. Charles, near Washington	30	1,065	.94	35	151	166	60	302	39	94	63	33	101	250	157
Chicago	Wabash, near Lake	50	7,561	2.08	151	35	38	14	70	9	22	15	8	23	58	35
Chicago	Clark, near Madison	45	6,398	1.46	142	37	41	15	74	10	23	16	8	25	61	37
Chicago	La Salle, near Locust	36	2,756	.90	77	68	75	27	136	18	42	29	15	46	113	68
Chicago	Dearborn, opposite Washington Park	38	2,604	1.11	69	76	84	30	152	20	48	32	16	51	126	76
Philadelphia	Broad, in front of Penn. R. R. Depot	65	9,237	1.52	142	37	41	15	74	10	23	16	8	25	61	37
Philadelphia	Filbert, in front of City Hall	65	6,302	1.24	97	54	59	22	108	14	37	23	12	36	90	54
Philadelphia	Chestnut, cor. of 4th	26	1,928	1.06	74	71	78	28	142	19	44	30	15	47	118	71

St. Louis	Locust, near Beaumont	36	3,691	1.13	103	51	56	20	102	13	39	21	11	34	85	51
St. Louis	Broadway, near Olive	50	3,618	1.23	72	73	80	29	146	19	46	31	16	49	121	73
St. Louis	Pine, near Garrison	36	2,551	1.16	70	76	84	30	152	20	48	32	16	51	126	76
St. Louis	Chestnut, near Beaumont	36	942	.90	27	196	216	78	392	51	122	82	42	124	325	196
St. Louis	Olive, near Beaumont	36	259	.84	7	760	836	304	1520	200	475	319	165	506	1260	760
Louisville	Main, near 3rd	61	4,176	1.25	69	77	84	31	154	20	48	32	17	51	128	77
Louisville	8th, near Walnut	36	2,402	1.05	67	79	87	32	158	21	49	33	17	53	123	79
Louisville	7th, near Jefferson	35	977	1.05	28	189	208	76	378	49	118	79	41	126	313	189
Washington	15th, opposite Treasury	70	4,622	1.02	66	81	89	32	162	21	51	34	18	54	135	81
Washington	9th, between D and E	50	1,688	.87	34	156	171	62	312	41	97	66	34	104	259	156
Washington	7th, between D and E	50	1,445	.88	29	183	201	73	360	48	114	77	40	122	304	183
Washington	6th, between Pa. and B	60	1,289	1.01	21	252	277	101	504	67	157	106	55	168	418	252
Buffalo	Main, near Swan	56	2,613	.83	47	113	124	45	226	29	71	47	25	75	188	113
Buffalo	Main, near Bouck	42	1,505	1.88	36	147	162	59	294	38	92	62	32	98	244	147
Buffalo	Linwood, near Ferry	38	825	1.47	22	241	265	96	482	63	151	101	52	161	400	241
Buffalo	Main, near Glenwood	50	714	1.24	14	378	416	151	756	99	236	158	82	252	627	378
Omaha	Douglass, near 15th	63	2,967	.62	47	113	124	45	226	29	71	47	25	75	188	113
Omaha	Farnham, near 14th	60	1,449	.59	24	221	243	88	442	58	138	93	48	147	366	221

believe that a brick will keep its place in a pavement until it is three fourths worn out.

Notice that if Captain Greene's estimates for the tonnage of "light-weight" and "medium-weight" vehicles are too great, as referred to above, then the quantities in columns 1–15 of Table VII are proportionally too small..

Table VII was extended to the full limit of all the available data, to afford the readers of this article a better opportunity for making comparisons. For example, a man who is personally familiar with the traffic of Broadway, New York City, by inspecting the top line of this table can form an opinion as to the durability of brick on that thoroughfare. Or a man who is personally acquainted with the wearing power of brick No. 10, or who manufactures a brick which gives the same results in the laboratory tests as No. 10, can judge of the durability of that brick under traffic of various intensity, by inspecting column 10 of the table.

Of course the the table is not infallible, but is intended only as a rough approximation. In fact all of the preceding discussion is offered as indicating a method by which the durability of brick paving may be investigated, rather than as affording definite conclusions. It is greatly to be desired that some firm or association or municipality shall undertake a thorough investigation of the durability and economy of brick as a paving material. Unquestionably bricks possess many characteristics which commend them for paving purposes. 1. They make a practically noiseless pavement. 2. They fit so close that there are no inter-spaces to retain filth and breed disease. 3. A brick pavement is easily cleaned. 4. A brick pavement is easily repaired. 5. The bricks can be made of any size and shape for gutters, slopes, etc., without much, if any, additional cost. 6. Brick pavements are so smooth as to reduce the tractive power, and wear and tear on vehicles almost to a minimum. 7. Bricks do not polish under wear, and hence always afford a good foot-hold to horses. 8. Good paving brick are not affected appreciably by moisture, frost, or fire. 9. The first cost of a brick pavement is less, at least in many localities, than any fairly durable pavement. Therefore, on the score of health and comfort, and first cost, brick pavements have much to commend them. The only debatable question is that of economy.

The economy of a pavement depends upon its first cost and upon the cost of maintenance. The first cost is an item that can readily be determined, in any particular case, with reasonable accuracy. But the first cost of a pavement is only one of the factors which determine its cost in a number of years. To determine this it is necessary to take account of the cost of maintenance and the interest on the first cost. It is said that in the twenty cities of this country which have a population of over 100,000 each, the pavements represent an investment of $250,000,000—a trifle over $40 per capita for the inhabitants of those cities. If the money value of the pavements of the other cities were added to the above value, the total would indeed be a large sum. Furthermore, there are many cities that at present are deterred from laying pavements owing to the great expense and unsatisfactory conditions of pavements in the past. All of this shows how important it is that pavements should fulfill, thoroughly and yet economically, the purposes for which they are designed.

The cost of maintenance depends upon the amount of traffic, the quality of the material, and the method of laying it. The last is the least important, but it is the one that has received the most attention. Whatever the kind of pavement, the volume of the traffic is a necessary element in determining the cost of maintenance. Unfortunately there are but few data on this subject, and what little there was taken according to such diverse systems as to rob them of much of the value that they might otherwise have. It is very desirable that those having charge of pavements should determine the amount, kind, etc., of traffic passing over them. Such data would be of very great value in determining the cost of maintenance.

We already have a fairly good knowledge of the qualities of many of the materials employed for paving, and are reasonably well versed in the method of testing them; but brick is a material only comparatively recently employed for paving purposes, at least in this country, and at present there is no standard by which to judge of its quality. One of the objects of this article has been to present some data bearing on this point; and if such data shall be useful or interesting to any one, or if this article shall stimulate others to make further investigations, it will not have been written in vain.

The data concerning the experiments below came to hand after the above article was completed, but are here added because of their interest and bearing upon a question of general interest. So far as the writer has observed the only reference in the literature of pavements to these experiments is a very brief item which has frequently been quoted in the technical press and in reports on the paving question.

ST. LOUIS EXPERIMENTS.*

§22. The city authorities of St. Louis, Mo., made some experiments in 1878 on the durability of brick pavement, by rolling a two-wheeled cart back and forth over narrow strips of the pavement to be tested. The wheels were 3 feet in diameter, and the tires were 2½ inches wide. To the axle of the cart was fastened a box into which weights could be placed. Observations having shown that in St. Louis the average load per wheel of loaded vehicles was 700 pounds per inch of width of tire, the weight in the box was ordinarily adjusted to give 800 pounds per inch of width of tire of the experimental machine. The cart was moved backward and forward over a space of 7 feet. The number of trip was recorded mechanically. The speed of the wheels changed from absolute rest at the end of each stroke to over 3 feet per second (somewhat over 2 miles per hour) at the center of the boxes. This is about the average speed of heavy vehicles.

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*The data concerning these experiments is derived from a manuscript copy of an official report to the Board of Public Improvements of the City of St. Louis, Mo., kindly loaned for this purpose by Hon. M. J. Murphy, Commissioner of Streets of St. Louis. The writer is under obligations to Mr. T. H. Macklind, engineer in charge of street reconstruction, for courtesies connected with the preparation of this part of this article.

The paving material to be tested was placed in boxes 8 feet long and 22 inches wide, in the clear, one of these boxes being placed under each wheel. To expose successively the whole surface of the material to the action of the wheels, the boxes were at certain intervals moved sideways by jack-screws.

The official report says: "The effects of temperature and moisture, which are very destructive on some kinds of material, are not taken into account in these tests. The tests of wood, asphaltum, and macadam made by the machine will, therefore, not give reliable results as to the life of these pavements, while those for block pavement of stone will give tolerably correct results." Since even fairly good paving brick are not appreciably affected by temperature and moisture when laid in sidewalks, it appears that the above tests should give approximately accurate relative results for brick as compared with granite.

The report above referred to makes the following statement concerning the traffic on the streets of St. Louis. No explanation is given of the way in which the traffic was determined. "Without counting unloaded vehicles and those provided with springs, which generally carry light loads and which under any circumstances have much less effect on a pavement than those without springs, * * the average daily tonnage carried over each foot in width of our pavements accommodating heavy traffic may be set down at 35 tons. * * * The injury to pavements by the hoofs of horses is estimated at about one third of that caused by wheels, and therefore the total abrading action of the wheels and horses combined may be set down as being 35 plus one third of 35, or say 50 tons per day per foot of width of pavement of streets carrying heavy traffic." Hence in comparing the results obtained with the cart above referred to, it was assumed that 50 tons of that artificial tonnage was equivalent to one day in the pavement of the average heavy traffic street of St. Louis.

Notice that the above estimate does not include "unloaded vehicles and those provided with springs," but assumes the effect of the horses' feet to be 15 tons per day per foot of width, *i. e.* assumes that the effect of the horses' feet is two sevenths of the effect of the wheels. It would seem that the former ought not to have been omitted and also that the latter is over estimated. However one error tends to neutralize the other, and the only thing that can be done now is to assume that one exactly neutralizes the other.

EXPERIMENT WITH BRICK AND ASPHALT BLOCKS.

§ 23. The first experiment was made with "asphaltum blocks" under one wheel of the cart and "bricks of fire-clay" under the other. The former were 4 inches wide, 5 inches deep, and 12 inches long. Twenty-three such blocks weighed 499 pounds. The bricks were 6 inches wide, 7 inches deep, and 8½ inches long. Nineteen such bricks weighed 496½ pounds. "The bricks being only 8½ inches long the travel of the wheels for both materials was necessarily confined to a strip of that width. The machine was set in motion without any load except the weight of the cart, amounting to say 700 pounds [140 per inch of tire], and in this condition made 41,979 revolutions, *i. e.*, each wheel made 83,958 trips over the material under test. The wheels were then loaded with 2,200 pounds of lead, making the total load 2,900 pounds [580 per inch of tire], and with this load the machine made 24,421 revolutions. Next 1,100 more pounds of lead were placed in the box, making the total weight on each wheel 2,000 pounds [800 per inch of tire], and under this load the machine made 54,955 revolutions."

In reducing the results the officials of St. Louis disregarded the wear when the cart was empty and also when the medium load was in the cart, but the writer of this sees no reason in so doing. With the lightest load the tonnage was 20,700 tons per foot of width—equivalent to 50 tons per foot of width for 1.1 years of 365 days (the length of year employed in the official report). With the medium load the tonnage was 49,990 tons—equivalent to 2.6 years. With the heaviest load the tonnage passing over the material being tested was 155,000 tons—equivalent to 50 tons per foot of width for 8.3 years. The total wear was then equivalent to a service of 1.1+2.6+8.3 =11.0 years in a pavement carrying a traffic of 50 tons per foot of width.

During the entire experiment the asphalt blocks lost 14 per cent of their weight, and the bricks lost 9 per cent. The total tonnage was 225,500 tons per foot of width. Therefore a tonnage of 16,100 tons per foot of width caused the asphalt blocks to lose 1 per cent., and 25,000 tons per foot of width wore 1 per cent. from the bricks. Compare the last result with those deduced in §§ 15, 16 and 17. Notice, however, that the traffic considered in §§ 15, 16 and 17, was actual travel in the street, while that considered in this section is artificial and does not include the effect of the horses' feet and the weather.

Before closing the discussion of this experiment, it is proper to record that "about one half of the brick broke into pieces, while only one asphaltum block was broken." On the other hand, it is only fair to record also that the maker of the brick claimed,* at the time the experiments were made, that the brick were an experimental lot and imperfectly made and "badly burned, so that he was not satisfied that they should go under the testing machine as they were, and requested that they might be broken up and tried as macadam, but owing to a misunderstanding they were put under as received."

NON-OFFICIAL EXPERIMENTS WITH BRICK.†

§ 24. The manufacturer of the above brick had others made of smaller size and under more favorable circumstances, which were tested with the same apparatus, at the same place, under exactly the same conditions as the official tests above. Thirty-five "hydraulic pressed brick" were placed under one wheel, and thirty-one "hand-made pressed brick" under the other. The cart was then moved back and forth, in the same track, until 146,000 transits had been recorded. This was a tonnage of 146,000 tons on 2½ inches, which is equivalent to 700,800 tons per foot of width —a tonnage equal to 35 years of a street carrying a daily traffic of 50 tons per foot. The loss was roughly measured and pronounced to be about one eighth of an inch for the "hand-made brick" and one quarter of an inch for the "hydraulic pressed brick." The experiment was then continued until the cart had made 148,692 transits—equivalent to 713,760 tons per foot of width. The wear of the "hand-made brick" was then "very carefully measured and the average was found to be 0.15 of an inch. 50 per cent. of the brick showed a wear less than 0.12 of an inch, 34 per cent. a wear between 0.16 and 0.19 of an inch, and 16 per cent. from 0.25 to 0.31 of an inch. Only three were broken."

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*See page 5 of printed copy of report of committees of engineers and citizens made to the Board of Public Improvements of St. Louis, on June 4th, 1881.

†The data for § § 23 and 24 are from pages 6–8 of the report just referred to above.

The brick were 4 inches deep. Therefore wearing off a depth of 0.15 of an inch from the "hand-made brick" was equivalent to wearing off 3.75 per cent. Then if 713,760 tons wore away 3.75 per cent., to wear away 1 per cent. required 190,000 tons. With the "hydraulic pressed brick" 95,000 tons caused a loss of 1 per cent. Comparing these results with those obtained in § 22, we see that these bricks were very much better than those employed in the official test.

The brick employed in this experiment are Nos. 4 and 5 of Table V (page 15).

§ 25. Brick of the same manufacture and apparently of the same quality as those employed in the test described in the preceding section, were laid in two portions of the streets of St. Louis as an experiment. The following quotations are extracts from the report of citizens and engineers appointed to examine these pavements:

"At your request we have examined a section of the Sattler brick pavement, 29 feet in length, on Second Street near Pine; and also a section on the track of the Pine Street horse railroad. According to your statements, both these pavements have been in use for *two years* and *twenty days*, without any change or repair during this time, except the change of position from the north side to the south side of Pine Street, the same surfaces being retained in their new positions. The bricks on Second Street are 4 inches wide, 4¼ inches deep, and 9 inches long. Those on Pine Street are 2¾ inches wide, 4⅝ inches deep, and 9 inches long. Those on Second Street are laid on the foundation boards of a former wooden pavement. Those on Pine Street seem to be laid on loose sand and dirt.

"In our presence there were dug up, with a steel-pointed crow-bar, a number of the brick from the Second Street pavement, in two different places, chosen as being the places where the *maximum* wear by hoof and wheel would, it was believed, be manifest. It is believed that no portion of any of our streets is subject to a *greater* and *harder* use that would both wear and break the material of the pavement than this. None of the bricks taken up were broken except as they were broken by the necessary blow of the crow-bar, handled for the purpose by strong men, in digging them up. Four of those taken up were placed so as to give their *com-*

bined height as worn, and by the side of them were placed four never used but of the same size. The difference between their respective heights was only *half an inch*, making only one eighth of an inch wear to each brick. The edges of the brick were broken off by their use, and the surfaces roughened just about enough, it would seem, to make good foot-holds for the horses.

"Bricks were taken up in our presence from the Pine Street track* and from the place selected, being the place which would, it was believed, be *most exposed* to the use and wear of vehicles turning the corners from Pine into Fifth Street, and from the latter into the former. The old and new were placed side by side as in the former case, and *no appreciable surface wear was found.* But the edges were broken, making good foot-hold for the horses. Drivers of the cars on this track, with the experience of all the seasons, being consulted, said that no portion of the track was so *pleasant* for the horses, and *safe from slipping* as this."

Let us see if we can arrive at any relation between the wear and the tonnage, for the Second Street pavement referred to above. In § 22 it was shown that the average traffic of the business streets of St. Louis was 35 tons per day per foot of width "without counting unloaded vehicles and those with springs." It seems that the omitted traffic would certainly amount to, at least, 15 tons; and hence we will assume that the total traffic was about 50 tons per day per foot of width. The loss *in surface wear* during two years was one eighth of an inch—equal to 2.8 per cent. of the depth of the brick. In this time there had probably passed over the pavement 50×365†×2=36,500 tons. According to this basis 13,000 tons wore off 1 per cent. (See § 15.)

The experimental pavement at the corner of Second and Pine was removed to make way for granite blocks and "was re-laid at the entrance of the Missouri Pacific R. R. freight house where the traffic is very heavy. After five years of hard service, the bricks show but little evidence of wear."‡

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*"NOTE—Two lines of cars pass over this track."

†The length of year employed in all of the official reductions of traffic experiments and observations is 365 days, and hence it is probable that the average tonnage was deduced on the same basis.

‡Report of J. E. Mohan on brick pavements read before a meeting of property-holders, January, 1888.

Nothing is known to the writer about the traffic over the brick pavement laid in the Pine Street horse-car track, and hence no estimate, not even an approximate one, can be made of the relation between tonnage and rate of wear. Apparently this pavement did not wear as much as that on Second Street, but perhaps the difference was only apparent and was due to errors of observation in determining the wear.

MACADAM.

§ 26. We will resume the consideration of the official tests made under the direction of the Board of Public Improvements of St. Louis—see §§ 22 and 23.

The second official experiment consisted in filling one of the boxes—depth 1 foot—with "limestone macadam broken to a size of 2½ and 3 inches, without any admixture; and in filling the other box with the same macadam, the interstices of which were filled with sand washed in."

In order to compact the material somewhat before allowing the concentrated pressure of the wheels to act on it, flat plates of iron were first placed on the material, and the wheels were allowed to travel over these plates for some time before being brought to act directly on the macadam. With the clear macadam the cart made 3,435 trips on the iron plate and 1,400 trips on the broken stone.

In building macadam roads it is the custom to thoroughly compact the broken stone by rolling before allowing traffic to pass over it. Probably no amount of rolling with the above machine with an iron plate intervening between the macadam and the wheels, would do more than compact the broken stone the amount customary in ordinary practice. Therefore, we will assume that the durability is fairly measured by the wear during the time the wheel was in contact with the macadam. In the beginning' the box contained 1,154 pounds of broken stone; and at the end of the experiment only 454 pounds remained uncrushed. The loss was, therefore, 700 pounds or 60 per cent. The area rolled was 7 feet by 22 inches, which is 12.67 square feet. The total tonnage was 1,400 tons on a width of 22 inches; or 75.5 tons per foot of width. Therefore the loss per square foot of exposed surface was 0.74 pounds of macadam per ton of traffic. Or, to state this result in another form, since 1,400 tons on 22 inches caused a loss of 60 per cent., 12.7 tons per foot of width caused a loss of 1 per cent. This result is comparable with those obtained in § 22, where it was shown that 25,000 tons were required to wear 1 per cent. from a brick pavement, and also that 16,100 tons wore 1 per cent. from the asphalt blocks.

The loss of the mixture of broken stone and sand was only 82 per cent. of that of the clear macadam; or, in other words, about 16 tons per foot of width were required to wear away 1 per cent.

In actual practice, the effect of temperature, moisture, wind, etc., would probably have very greatly increased the loss of the macadam. However, the official report says: "The value of the experiments with the macadam is somewhat doubtful for several reasons [one of which was that "very inferior macadam" was employed.] * * However, the experiments, even if it be conceded they were made under circumstances adverse to the macadam, can not fail to impress every one very strongly with the utter worthlessness of this material for paving purposes on streets traveled by heavily loaded teams."

LIMESTONE BLOCKS AND GRANITE BLOCKS.

§ 27. The third experiment was made upon limestone and granite blocks. The blocks were 4 inches wide, 7 to 14 inches long, and 7 to 8 inches deep. All were firmly set in a bed of sand. After the machine had made 81,460 trips, the loss of the granite was inappreciable, while the limestone had lost 10.1 per cent. Therefore 4,400 tons per foot of width caused the limestone blocks to lose 1 per cent. Compare this result with those it §§ 23 and 26.

§ 28. The fourth experiment was made by substituting patent wood blocks (4×6×12 inches) for the limestone blocks of the preceding experiment, and continuing the granite blocks. The passage of 94,285 tons caused the wood to lose 4 per cent.; or 12,900 tons per foot of width caused a loss of 1 per cent. The total tonnage over the granite was 175,745 tons, which caused a loss of 1.4 per cent., or 70,000 tons caused a loss of 1 per cent.

TABLE VIII.

Summary of the St. Louis Experiments, Showing the Artificial Tonnage per Foot of Width Required to Wear 1 Per Cent. from the Several Materials.

Ref. No.	Materials.	Tons.
1	Limestone Macadam, clear	13
2	“ “ with sand	16
3	“ Blocks	4,400
4	Patent Wood Blocks	12,900
5	Asphaltum Blocks	16,100
6	Sattler's Brick (official test)	25,000
7	Granite Block	70,000
8	Sattler's Brick, “hydraulic pressed” (non-official test.)	95,000
9	Sattler's Brick, “hand-pressed” (non-official test.)	190,000